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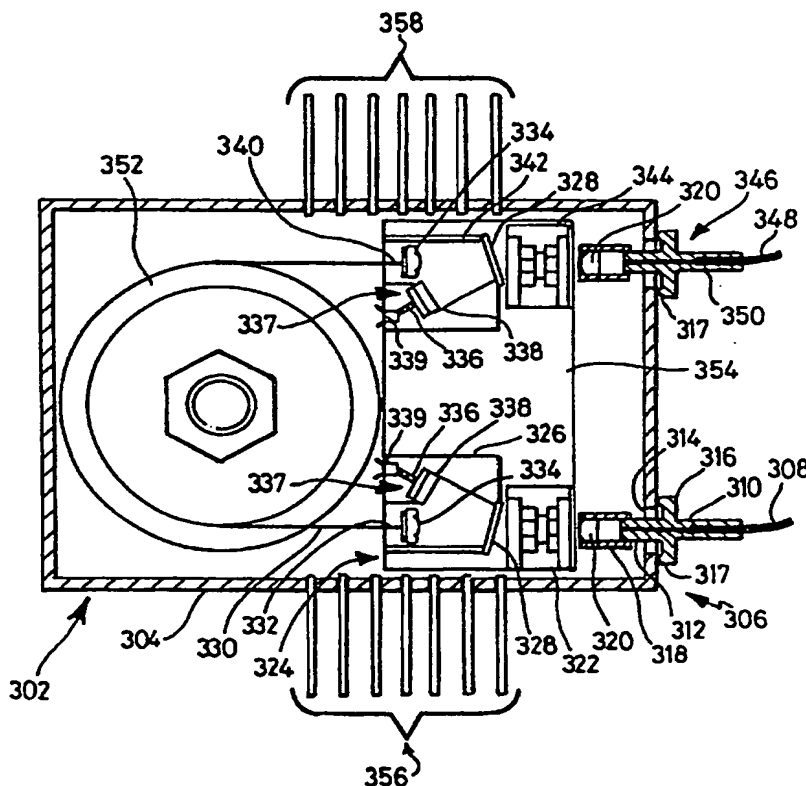
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(54) Title: PACKAGED OPTICAL AMPLIFIER ASSEMBLY

(57) Abstract

A packaged optical amplifier assembly includes an erbium doped silica based optical amplifying fibre (330) co-pumped and counter-pumped by a pair of laser diodes (336) as optical pumps. The optical pumps (336) are each coupled to an end (332, 340) of the fibre (330) by reflection from a dichroic mirror (328), the optical signal being collimated and arranged to propagate unguided between the input (306) and the first end (332), and the second end (340) and the output (346), and optical pump light from each optical pump (336) being collimated and arranged to propagate unguided between the optical pump (336) and the end of the fibre (332, 340) to which it is coupled.



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Packaged Optical Amplifier Assembly

This invention relates to packaged optical amplifier
5 assemblies to which an optical signal can be applied at an
input and an amplified optical signal is provided at an
output. The invention relates particularly to optical
amplifier assemblies in which amplification is provided by
means of an optical amplifying fibre pumped by an optical
10 pump.

The process of optical amplification by optical amplifying
fibres is well known and will not be described in detail in
this application. In broad terms, the core region of the
15 optical fibre contains a dopant, for example erbium ions,
which once optically excited can provide optical gain to an
optical signal of suitable wavelength propagating along the
fibre. The dopant is excited by passing an optical pump
signal of a suitable wavelength along the fibre. For
20 example, an erbium doped fibre can provide amplification to
optical signals of wavelengths in the range 1520nm to
1580nm when pumped by an optical pump signal of wavelength
of about 1480nm or 980nm. Suitable fibres and optical
pumps for providing amplification at various wavelengths
25 are readily available commercially.

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A currently available packaged optical amplifier assembly is shown schematically at Figures 1 and 2. It includes a number of commercially available optical components whose pigtailed are spliced together to form the required optical circuit for the amplifier. Figure 1 shows, schematically, an assembled packaged optical amplifier 102. Figure 2 shows the components of the package of Figure 1 laid out as a key to show more clearly how the components are interconnected.

10

The optical amplifier assembly 102 is packaged in a housing comprising two interlocking metal compartments 104 and 106, the former holding passive optical components, the latter holding a printed circuit board (PCB) 108 on which are mounted optical components with electrical connections. The associated electronic components on the PCB are not shown. Fibre splices will be indicated by reference to the splice protectors which surround them.

Optical signals to be amplified by the optical amplifier assembly 102 are coupled to an input pigtail 110 by connecting to it a source optical fibre (not shown). The input pigtail 110 is coupled to the input pigtail of an input isolator 112 by splice 114, the output pigtail of which is coupled to a first pigtail of an input dichroic

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wavelength division multiplexer (WDM) 116 by splice 118. The output pigtail of a first laser diode optical pump 120 is coupled to a second pigtail of the dichroic WDM 116 by a splice 122. The WDM 116 outputs a combined input optical
5 signal and optical pump signal at a third pigtail which is spliced to a first end 124 of a 30m long erbium-doped, silica based fibre 126 by a splice 128.

The amplifying fibre 126 is wound on a pair of bobbins 130
10 and 132.

A second end 134 of the amplifying fibre 126 is coupled to a first pigtail of an output dichroic WDM 136 by a splice 137. The output pigtail of a second laser diode optical
15 pump 138 is coupled to a second pigtail of the output WDM 136 by a splice 139. The output WDM 136 outputs the optical pump signal to the second end 134 of the amplifying fibre 126 whilst outputting an amplified optical signal received from the second end 134 of the amplifying fibre
20 126 to an output optical isolator 140, the pigtails of the output WDM 136 and output isolator 140 being coupled by a splice 142.

The output pigtail of the output isolator 140 is coupled to
25 the input pigtail of an optical fibre coupler 144 by a

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splice 146. One output pigtail of the coupler 144 is coupled to the input pigtail of a monitor diode 148 by a splice 150, a second output pigtail of the coupler 144 being coupled to an output pigtail 152 of the packaged
5 amplifier 102 by a splice 154.

The optical pump 120 co-pumps the amplifying fibre 126 whilst the optical pump 138 counter-pumps the amplifying fibre 126.

10

There are several disadvantages associated with such prior art assemblies. The packages are bulky because of the constraints set by the minimum radius of curvature of the pigtails of the optical components.

15

The requirement to couple the input isolator to the input WDM produces a circle of fibre about 66mm in diameter which together with the length of the optical devices and the splice protectors places a constraint on the package
20 dimensions in the plane of the circle of the fibres. The need to couple the devices via their prepackaged pigtail input and output fibres means the optical signals undergo many transitions between guided and non-guided (free) propagation at collimating lenses within the packaged
25 optical components.

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Each optical isolator has two, and each WDM at least two and sometimes three, collimators, arranged at each of their inputs and outputs. There is also a need to splice the various pigtails together which is a labour intensive
5 operation.

The present invention seeks to provide a more compact packaged optical amplifier assembly. Accordingly there is provided a packaged optical amplifier assembly for
10 amplifying an optical signal the assembly having an input, an output, an optical amplifying fibre having ends coupled to the input and output, respectively, and an optical pump coupled to one of the ends of the fibre, the optical signal being collimated and arranged to propagate unguided between
15 said one of the ends and whichever of the input and the output is coupled to said one of the ends, and optical pump light from the optical pump being collimated and arranged to propagate unguided between the optical pump and the end of the fibre to which it is coupled and in which the
20 optical pump light and optical signal are combined by a dichroic mirror.

There may be pumps coupled to both the first and second ends of the fibre.

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The provision of such optical coupling of the input, output, and pump sources to the appropriate first and second ends of the fibre eliminates the requirement for fibre guiding between the components thus reducing the number of collimating lenses compared to an equivalent prior art assembly and consequently the number of guided to unguided transitions. Also, the only curved fibre component is the amplifying optical fibre which can be bent to a circle of diameter in the order of 30mm, compared to about 60mm for a common transmission fibre, thus allowing the dimensions of the package to be greatly reduced.

If a single optical pump is used it can be coupled to the first or to the second end of the optical amplifying fibre. It is not unusual however, to input pump power at both ends of the amplifying fibre.

Each optical pump is preferably located to minimise the angle of reflection of the pump signal by the dichroic mirror and the angle the mirror presents to the optical signal propagating through the mirror to minimise polarisation effects on reflection and transmission, for example by locating them adjacent to the end of the fibre to which it is optically coupled.

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It is convenient to arrange the optical axes of the input and first end of the fibre, and of the output and the second end of the fibre, to be coincident but it is also possible to set them at an angle with a highly reflecting
5 mirror between them. This would allow the input and output to be at right angles to the optical axes of the ends of the fibre if preferred.

The optical pump light may be reflected from an auxiliary
10 mirror before being combined with the optical signal by the dichroic mirror. The use of such an auxiliary mirror makes it easier to align the pump light with the optical signal.

The 980nm semiconductor pump lasers are particularly
15 susceptible to degradation if organic compounds contaminate their surfaces. It is preferable then, that each pump laser is contained within an hermetically sealed sub-package within the optical amplifier assembly package. The dichroic mirror coupling the optical pump to the amplifying
20 fibre may form an optical window in this hermetically sealed sub-package. Preferably however each pump laser is contained within a separate hermetically sealed sub-package within the optical amplifier assembly package with the lenses which collimate the optical pump light forming
25 optical windows in the sub-packages.

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It is usual to incorporate optical isolators at the input and output of the optical amplifier assembly as described above with reference to Figures 1 and 2. It has been found to be beneficial to mount such isolators with the optical
5 pumps on a common thermoelectric cooling means to reduce the temperature dependency of the isolators' performance.

A novel optical isolator which may be used in other applications but which is particularly suitable for use
10 with the optical amplifier assembly of the present invention comprises a housing having a through-hole, and a 45° Faraday rotator comprising a disc of magneto-optically active material located within the through-hole by a pair of annular permanent magnets, one on either side of the
15 disc.

Such an isolator is particularly compact and easy to assemble and by operating on non-guided optical signals can be simply interposed in the apparatus of the present
20 invention between the input and the first end of the fibre, and the second end of the fibre and the output, without the need for additional collimating lenses. It is to be noted that such an isolator could be employed in optical apparatus other than the optical amplifier apparatus of the
25 present invention. Its use is optional, but preferred,

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with the amplifier assembly of the present invention.

An embodiment of the invention will now be described, by way of example only, with reference to the accompanying
5 drawings of which:

Figure 1 is a schematic diagram of a prior art packaged optical fibre amplifier assembly;

10 Figure 2 is a schematic diagram showing the interconnections of the optical components of the assembly of Figure 1;

15 Figure 3 is a schematic sectional plan view of a packaged optical fibre amplifier assembly in accordance with the present invention;

20 Figure 4 is a schematic sectional plan view of a packaged optical fibre amplifier assembly in accordance with an alternative embodiment of the present invention;

25 Figure 5 is schematic sectional view of an optical isolator suitable for use with the optical fibre amplifier assembly of either Figure 3 or Figure 4; and

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Figure 6 is a schematic end view of the optical isolator of Figure 5 viewed in the direction V-V in Figure 5.

- 5 Referring to Figure 3 which shows an embodiment of the present invention, a packaged optical amplifier assembly 302 is housed in a metal housing 304. The lid of the housing is not shown.
- 10 An optical signal to be amplified is coupled to an input 306 via a pigtail optical fibre 308 which is hermetically sealed with glass solder (not shown) within a metal feedthrough 310 which has a tubular portion 312 passing through a circular aperture 314 in the housing 304. The
- 15 feedthrough 310 has an annular flange 316 of radius greater than the aperture 314 an outer raised rim 317 which is projection welded to the housing 304 once the feedthrough 310 has been aligned within the aperture 314.
- 20 A tubular collar 318, initially a sliding fit on the outside of the tubular portion 312 of the feedthrough 310, supports within it a collimating lens 320 at the end of the collar 318 distant from the feedthrough 310. The collar 318 is adjusted longitudinally on the feedthrough 310 until
- 25 positioned to accurately collimate light exiting the fibre

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308 whereupon it is fixed in position on the feedthrough 310. Collimated light from the collimating lens 320 propagates through an optical isolator 322 (which will be described in detail later) to an optical multiplexer 324.

5

The optical multiplexer 324 comprises a sub-carrier 326 with a dichroic mirror 328 (a multilayer, high pass filter) which transmits light of a frequency to be amplified by an erbium-doped amplifying optical fibre 330 a first end 332 of which extends into, and is attached to, the sub-carrier 326. Erbium-doped fibre is obtainable from Lycom A/S, NKT Alle 75, DK-2605, Brøndby, Denmark and Fibrecore Ltd., York House, School Lane, Chandlers Ford, Hampshire SO5 3DG, England, for example. A lens 334 couples light propagating from the collimating lens 320 into the amplifying fibre 330.

Also included in the housing 325 is a 1480nm diode laser 336, which may be mounted in an hermetically sealed sub-package. Suitable lasers are manufactured by Hewlett-Packard Ltd., Whitehouse Road, Ipswich, Suffolk IP1 5PB, England and Lasertron, 37 North Avenue, Burlington, MA 01803, USA, for example. The laser 325 is the optical pump for the amplifying fibre 330 in this exemplary embodiment of the present invention. The optical pump power from the

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laser 336 is collimated by a lens 338 (which may be sealed in the same sub-package as the laser 336) and reflected by the dichroic mirror to the lens 334 associated with the first end 332 of the amplifying fibre 330 and so is coupled
5 into the fibre 330. A pump monitor diode 339 is used to monitor the optical output of the laser diode 336 in known manner.

An optical signal propagates along the fibre 330 to a
10 second end 340 which is mounted on a sub-carrier 342 which is the mirror image (along the axis of the fibre end 340) to sub-carrier 326 and whose components have been accorded the same reference numerals as the corresponding components of sub-carrier 326. The optical pump power from the laser 336
15 of the sub-carrier 342 is coupled to the second end 340 of the fibre 330 via the dichroic mirror 328. In this case, the optical signal exits the second end 340 of the fibre 330, is collimated by lens 334 and is transmitted through the dichroic mirror 328 via an optical isolator 344 to an
20 output 346 of the amplifying assembly 302. The optical isolator 344 and output 346 are the same as the optical isolator 322 and input 306. The lens 320 of the output 346 couples the optical signal from the second end 340 of the fibre 330 to an output fibre 348 sealed within a
25 feedthrough 350 which is exactly the same as feedthrough

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306 and aligned and fixed to the housing 304 in the same manner.

In the present embodiment there are two pump lasers 336,
5 one co-pumping and the other counter-pumping the fibre 330 but only one of these need be used.

The amplifying fibre 330 is a 20m long silica based erbium doped optical fibre, wound on a 15mm radius bobbin 352.

10

The sub-carriers 326 and 342 and optical isolators 322 and 344 are all mounted on a common thermoelectric cooler 354 to provide relatively temperature insensitive operation to the performance of the amplifying assembly 302.

15

The various electrical inputs and outputs to and from the laser diodes 336, monitor diodes 339 and thermoelectric cooler 354 are provided at sets of electrical leads 356 and 358. The leads 356 and 358 are sealed to the housing 304
20 by glass solder seals in known manner. The housing 302 is of a metal whose thermal expansion matches that of the glass solder, for example Kovar (trademark).

Figure 4 shows an assembly 502 which corresponds
25 substantially to the assembly 302 of Figure 3. Components

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which are common to both the assemblies of Figures 3 and 4 will not be describe again. However the assembly 502 has sub-carriers 526 and 542 which differ from the corresponding sub-assemblies in Figure 3, and these sub-
5 carriers will be described below.

Each sub-assembly has a dichroic mirror 528 mounted in the light path between a collimating lens 320 and a lens 534 at each end of the fibre. A laser 536 is mounted in the sub-
10 assembly and has its output directed to a mirror 560. The mirrors 528 and 560 are angled to reflect the light from the laser 536 so that it is aligned with the light passing between the collimating lens 320 and the lens 534. Both these mirrors are adjustable to enable this alignment to be
15 achieved.

The alignment required is that of parallelness and colinearity. This requires adjustment of four degrees of freedom; movement in two orthogonal planes to produce
20 parallelness and movement about two orthogonal axes to produce colinearity. This adjustment can be achieved with the arrangement of Figure 3, but it may require adjustment of the position of the laser 336 itself. In order to ensure good thermal conduction between the laser and the
25 cooler 354, the laser should be permanently fixed to the

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cooler. The use of the auxiliary mirror 560 of Figure 4 allows the laser to be permanently fixed in position and the alignment to be achieved by moving the mirrors 528 and 560.

5

The isolators 322 and 344 are identical and will now be described with reference to Figures 5 and 6.

10 An isolator housing 458 has a circular through-hole 460 including an annular ridge 462 protruding into the through-hole 460 at its mid point. A 400nm thick plate, here in the form of a disc, of rare-earth iron garnet 466 of the same thickness as the ridge 462 and whose outer radius is the same as the inner radius of the ridge 462 is held in
15 position by a pair of annular ferromagnets 468, one each side of the disc 460, whose outer radii equal the radius of the through-hole 460 and whose inner radii are smaller than the radius of the disc 460.

20 The ferromagnets 468 have outer surfaces flush with outer portions 470 of the housing 458 so they can be retained by the planar surfaces of birefringent, tapered plates 472 of rutile or calcite, for example. The plates 472 are laterally located on the surfaces to housing 458 by
25 shoulders 474 against which one end of each plate 472

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abuts. The plates 472 are glued to the housing 458 to form the completed optical isolator 332 or 342 of Figure 3.

The disc 466 and ferromagnets 468 are dimensioned and
5 designed to form a 45° Faraday rotator in known manner.
The tapered birefringent plates constitute polarisers which
provide polarisation independent optical isolation in the
manner described in detail in US-4,548,478. Other
polarising means may be employed for example polarising
10 sheets such as 200nm Polacor (trademark) sheet. The
various optical surfaces of the optical components are
provided with antireflection coatings in known manner.

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CLAIMS

1. A packaged optical amplifier assembly for amplifying an optical signal, the assembly having an input (306), an output (346), an optical amplifying fibre (330) having ends
5 (332,340) coupled to the input (306) and output (346), respectively, and an optical pump (336) coupled to one of the ends (332,340) of the fibre, the optical signal being collimated and arranged to propagate unguided between said one of the ends and whichever of the input (306) and the
10 output (346) is coupled to said one of the ends, and optical pump light from the optical pump (336) being collimated and arranged to propagate unguided between the optical pump (336) and the end of the fibre (332, 340) to which it is coupled and in which the optical pump light and
15 optical signal are combined by a dichroic mirror (328).
2. An assembly as claimed in Claim 1 in which the optical pump light from the optical pump (536) is directed at an auxiliary mirror (560) and is reflected by the auxiliary
20 mirror to a dichroic mirror (528) where the optical pump light is combined with the optical signal.
3. An assembly as claimed in Claim 1 or Claim 2 in which the optical pump (336) is coupled to the first end (332) of
25 the optical amplifying fibre (330).

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4. An assembly as claimed in Claim 1 or Claim 2 in which the optical pump (336) is coupled to the second end (340) of the optical amplifying fibre (330).
- 5 5. An assembly as claimed in Claim 1 or Claim 2 in which there are two optical pumps (346), one coupled to each of the first end (332) and second end (340) of the optical amplifying fibre (330).
- 10 6. An assembly as claimed in any preceding claim in which each optical pump (336) is located adjacent the end (332, 340) of the optical amplifying fibre (330) to which it is optically coupled.
- 15 7. An assembly as claimed in any preceding claim in which the optical axes of the input (306) and first end (332) of the optical amplifying fibre (330), and the optical axes of the output (346) and the second end (340) of the optical amplifying fibre (330), are coincident.
- 20 8. An assembly as claimed in any preceding claim in which each optical pump (346) is hermetically sealed within the packaged optical amplifier assembly.
- 25 9. An assembly as claimed in Claim 8 in which each

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optical pump (336) is located within an hermetically sealed sub-package (337).

10. An assembly as claimed in Claim 9 wherein an optical
5 window is formed in the sub-package (337) by a collimating lens (338) which collimates the light from the optical pump (336).

11. An assembly as claimed in Claim 9 wherein an optical
10 window is formed in the sub-package (337) by the dichroic mirror (328).

12. An assembly as claimed in any preceding claim in which there is an optical isolator (322, 344) between either or
15 both of

- (i) the input (306) and the first end (332) of the optical amplifying fibre (330), and
- (ii) the second end (340) of the optical amplifying fibre (330) and the output (346).

20

13. An assembly as claimed in Claim 12 in which each optical pump (336) and each optical isolator (326, 344) is mounted on a common thermoelectric cooling means (354).

25 14. An optical isolator comprising a housing (458) having

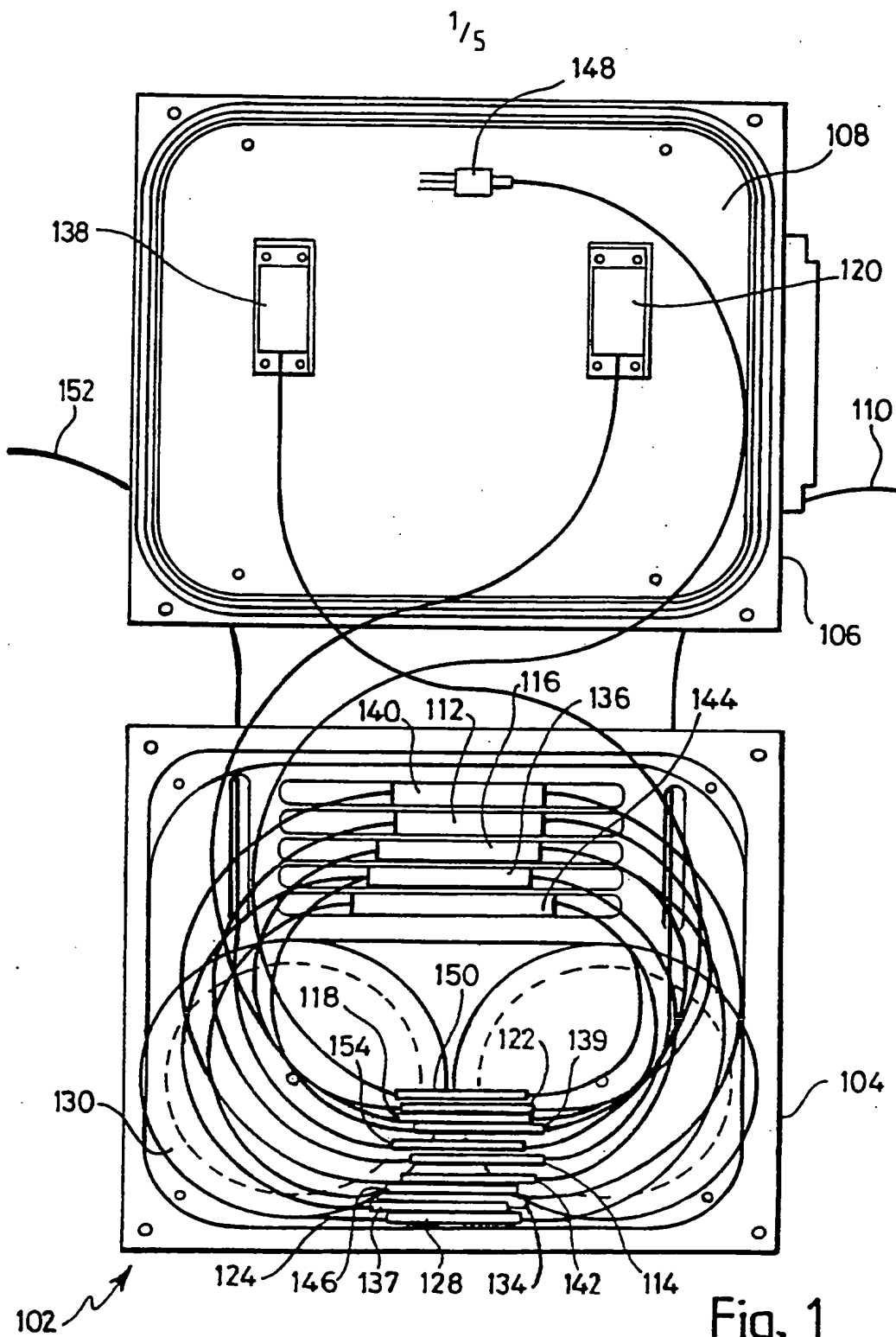
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a through-hole (460) with annular ridge (462) extending into the through-hole, a 45° Faraday rotator comprising a plate (466) of magneto-optically active material and located within the through-hole (460) by a pair of annular
5 permanent magnets (468), one on either side of the plate (466).

15. An optical isolator as claimed in Claim 14 including polarising plates (472) laterally located on the housing
10 (458) by a shoulder (474) against which a side of each plate (472) abuts, with the magnets being located between plates and the rotator.

16. An optical isolator as claimed in Claim 15 in which
15 the polarising plates (472) are tapered plates of birefringent material.

17. A packaged optical amplifier assembly for amplifying an optical signal, including an optical isolator as claimed
20 in any one of Claims 14 to 16.



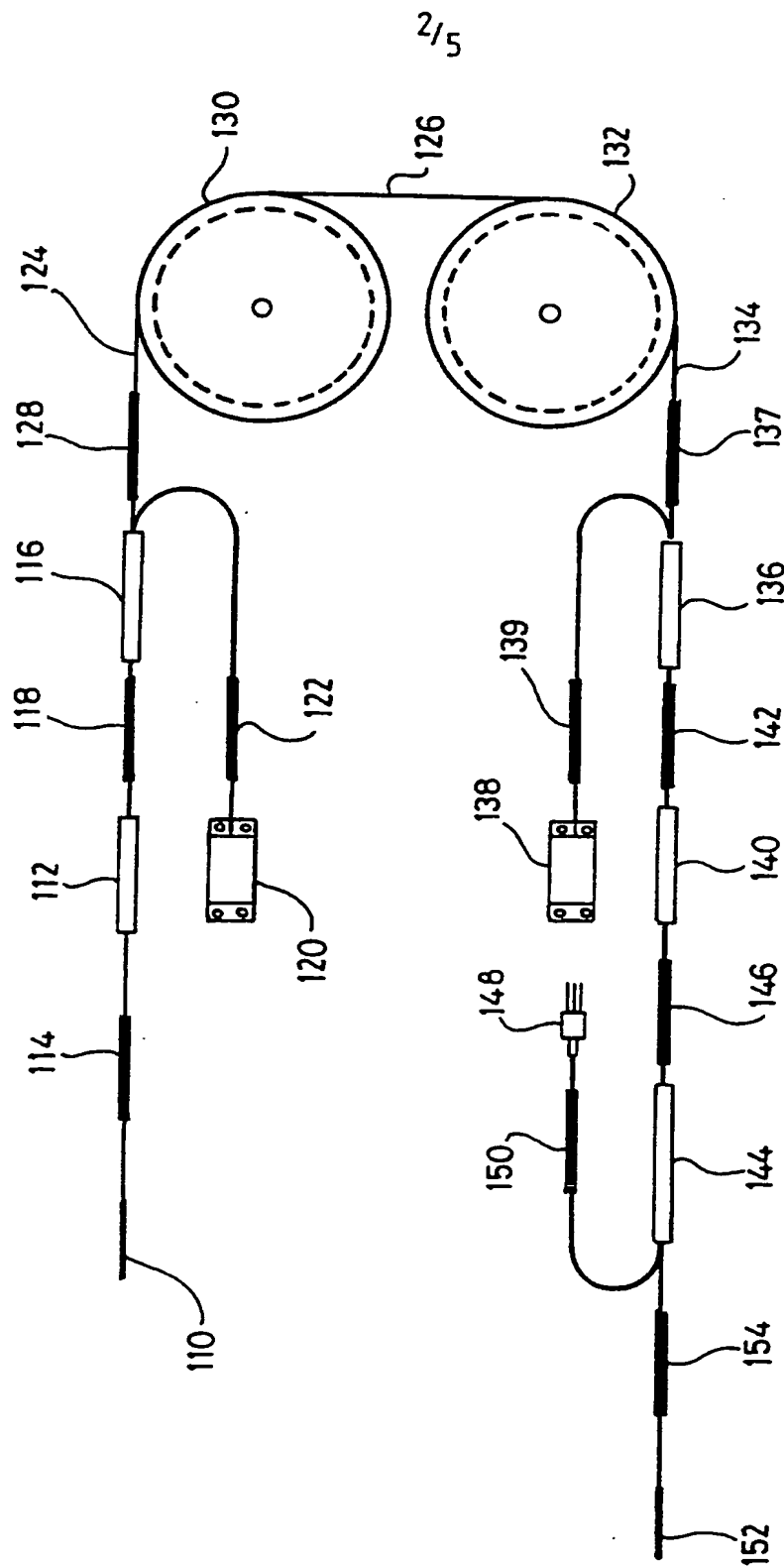


Fig. 2

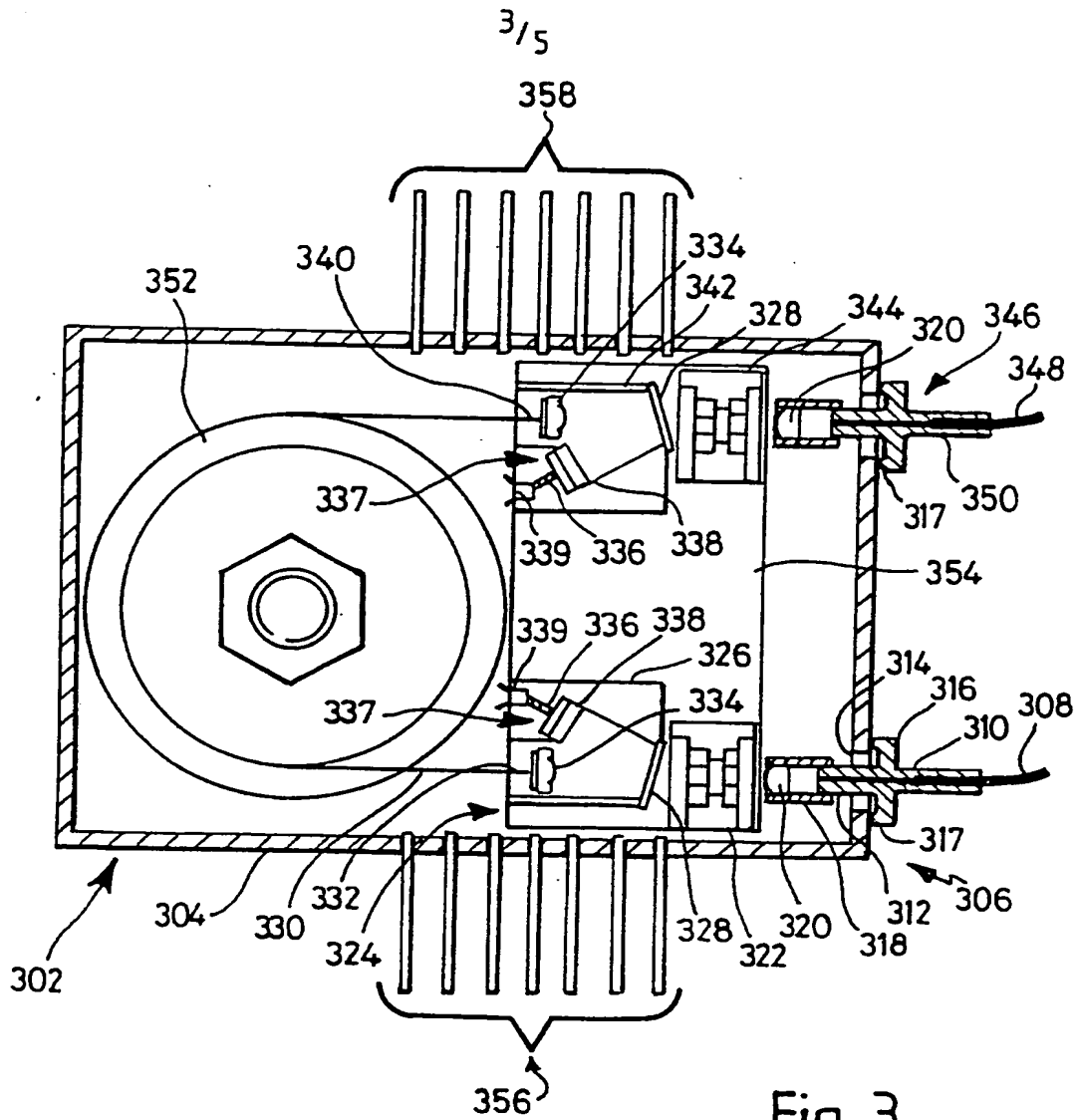


Fig. 3

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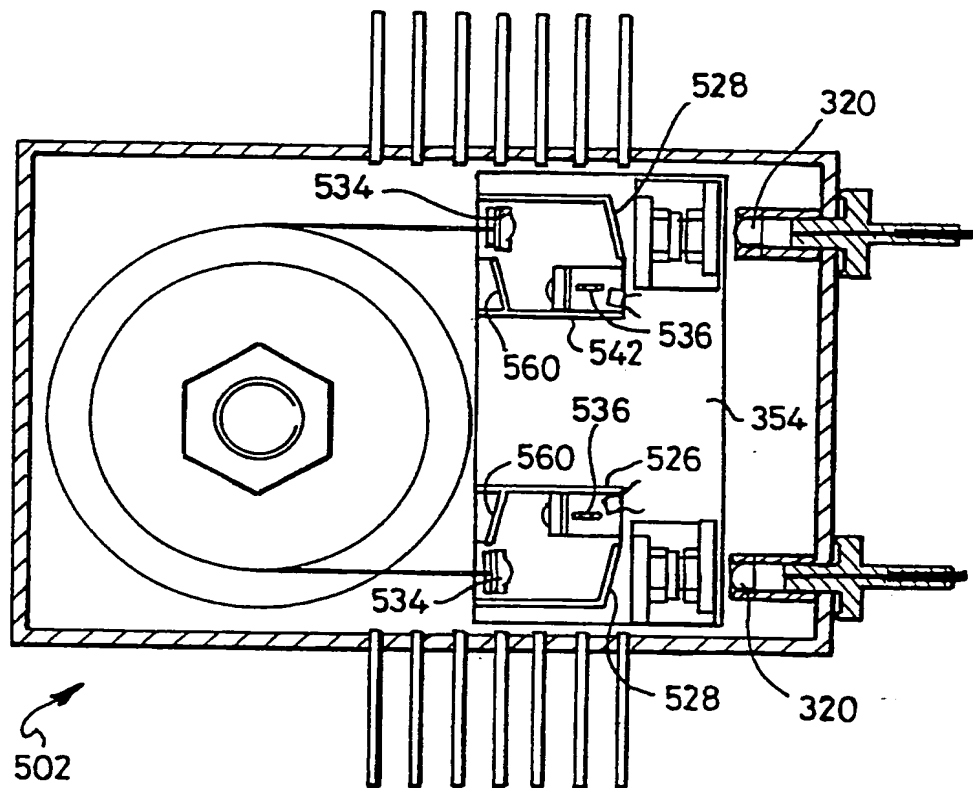
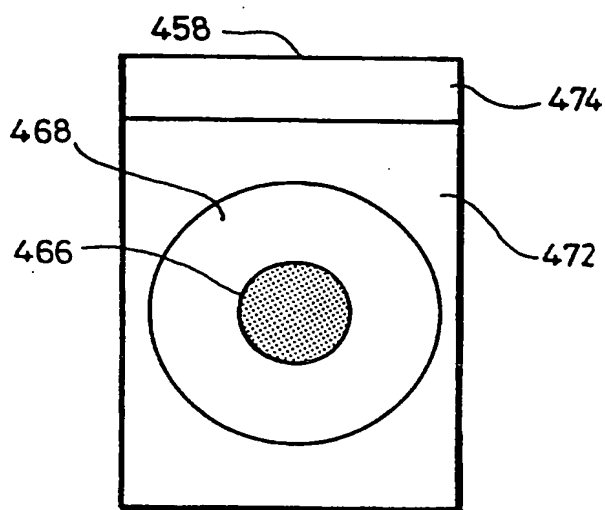
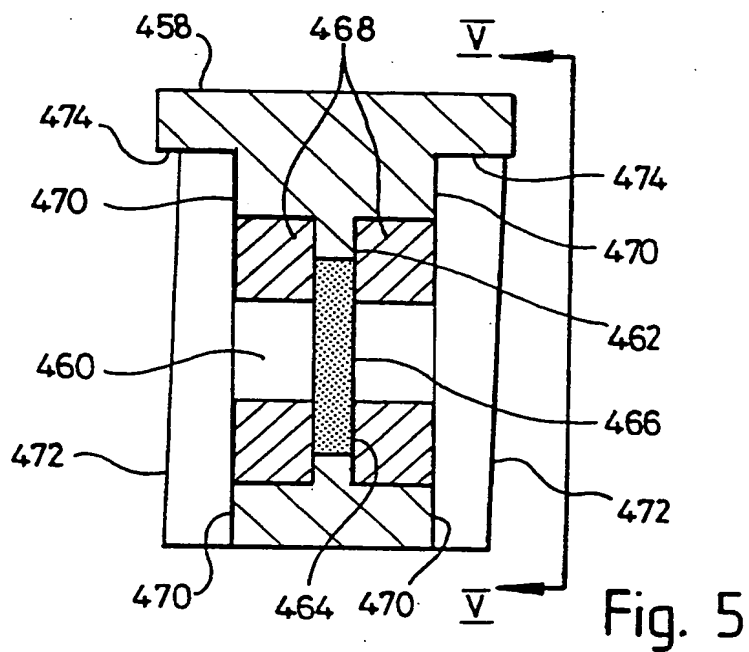


Fig. 4

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INTERNATIONAL SEARCH REPORT

Inter national Application No
PCT/GB 95/01407

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01S3/06 G02F1/09

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 H01S G02B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	PATENT ABSTRACTS OF JAPAN vol. 13, no. 214 (P-1209) 31 May 1991 & JP,A,03 059 547 (NTT) see abstract ---	1,3,7,12
Y	EP,A,0 409 258 (SUMITOMO) 23 January 1991 see column 4, line 44 - column 5, line 10 see column 5, line 42 - line 57 see figures 2,3 ---	1,3,7,12
A	EP,A,0 586 713 (NIPPON PETROCHEMICALS) 16 March 1994 see page 5, line 24 - line 30 see figure 2 --- -/--	2

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
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- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
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- * & * document member of the same patent family

Date of the actual completion of the international search

31 October 1995

Date of mailing of the international search report

08.11.95

Name and mailing address of the ISA

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 95/01407

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP,A,0 508 149 (GENERAL INSTRUMENT) 14 October 1992 see column 4, line 36 - column 5, line 43 see figure 1 ----	4,5
A	EP,A,0 563 524 (ALCATEL) 6 October 1993 see column 5, line 54 - column 6, line 20 see figure 1 ----	13
A	EP,A,0 444 694 (FUJITSU) 4 September 1991 see column 6, line 20 - column 7, line 25 see figure 3 ----	1
A	FR,A,2 678 075 (HITACHI) 24 December 1992 see page 10, line 21 - page 11, line 35 see figure 1 ----	14
A	OPTICAL FIBER COMMUNICATION CONFERENCE, Houston, Texas, 6-9 february 1989, Technical Digest Series, Volume 5 Conference Edition, Optical Society of America, Washington DC, W.L. Emkey et al.: 'In-line (pigtailed) polarization-independent optical isolator', page 149 see the whole article ----	14-16
A	GB,A,2 138 585 (RAYTHEON) 24 October 1984 see page 1, line 101 - line 109 see figure 1 ----	14
A	US,A,4 804 256 (WILSON) 14 February 1989 see column 3, line 38 - column 4, line 9 see figure 3 ----	14
A	EP,A,0 520 199 (MITSUBISHI) 30 December 1992 see column 18, line 38 - column 19, line 26 see figure 11 ----	14
A	US,A,5 105 307 (NISHIYAMA) 14 April 1992 see column 3, line 38 - line 60 see figure 1 ----	14
A	EP,A,0 372 448 (ALCATEL) 13 June 1990 see column 9, line 20 - line 30 see figure 7 -----	13,14

INTERNATIONAL SEARCH REPORT

International application No.

PCT/GB95/01407

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

claims 1-13
claims 14-17

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/GB 95/01407

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